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FLUID FLOW MODEL BASED ON THE ANALYSIS OF WATER INJECTION DATA IN THE TURONIAN RESERVOIR OF THE LIAWENDA FIELD, OFFSHORE COASTAL BASIN OF D.R. CONGO

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ABSTRACT

Arranged the hydrocarbons in an oil reservoir require several techniques for their exploitation. The Liawenda field, discovered in December 1971 following the drilling of the Liawenda-01 exploration well, has a total of 186 wells with an annual production of 3,009,553 barrels. Having started production several years ago, the field has used the water injection technique following a drop in pressure. Despite this recourse to water injection methods, production from the Liawenda field is not always satisfactory. Knowledge of fluid flow inside an oil reservoir is important because it enables us to estimate certain useful parameters that can determine fluid movements in order to identify the causes of excessive water production. Thus, the present paper deals with water injection data in order to understand fluid movements in the Turonian reservoir of the Liawenda Field:

- What is the fluid movement like in the Turonian reservoir of the Liawenda Field?
- How does water move in relation to oil?
- What are the efficiencies of fluid movement within the Liawenda Field?
- What is the speed and travel time of the fluids in this reservoir?
- How mobile are fluids?

Keywords: Permeability, Liawenda, Turonian reservoir, injection, oil field

INTRODUCTION

In the oil industry, waterflooding is a technique that generally makes it possible to increase the pressure in the oilfield, thereby boosting production. Water injection wells can be found both onshore and offshore, to increase oil recovery from an existing reservoir. Water is injected to maintain reservoir pressure, but also to sweep or displace oil from the reservoir and push it towards a well [2]. Located in the Province of Kongo Central, the DR Congo Coastal Basin (Figure 1) has several onshore and offshore oil fields. One of these is the Liawenda Field, which has several wells producing from the two major reservoirs (Turonian and Cenomanian). Discovered in December 1971 following exploration drilling of the Liawenda-01 well, the Liawenda field has a total of 186 wells with annual production of 3,009,553 barrels. Having started production several years ago, the field has used the water injection technique following a drop in pressure. Despite this recourse to water injection methods, production from the Liawenda field is not always satisfactory. However, excessive production of water in relation to oil has been observed [13]. Knowledge of fluid flow inside an oil reservoir is important because it enables us to estimate certain useful parameters that can determine fluid movements and thus identify the causes of excessive water production. In this paper, water injection data are used to determine fluid movement in the Turonian reservoir of the Liawenda Field.

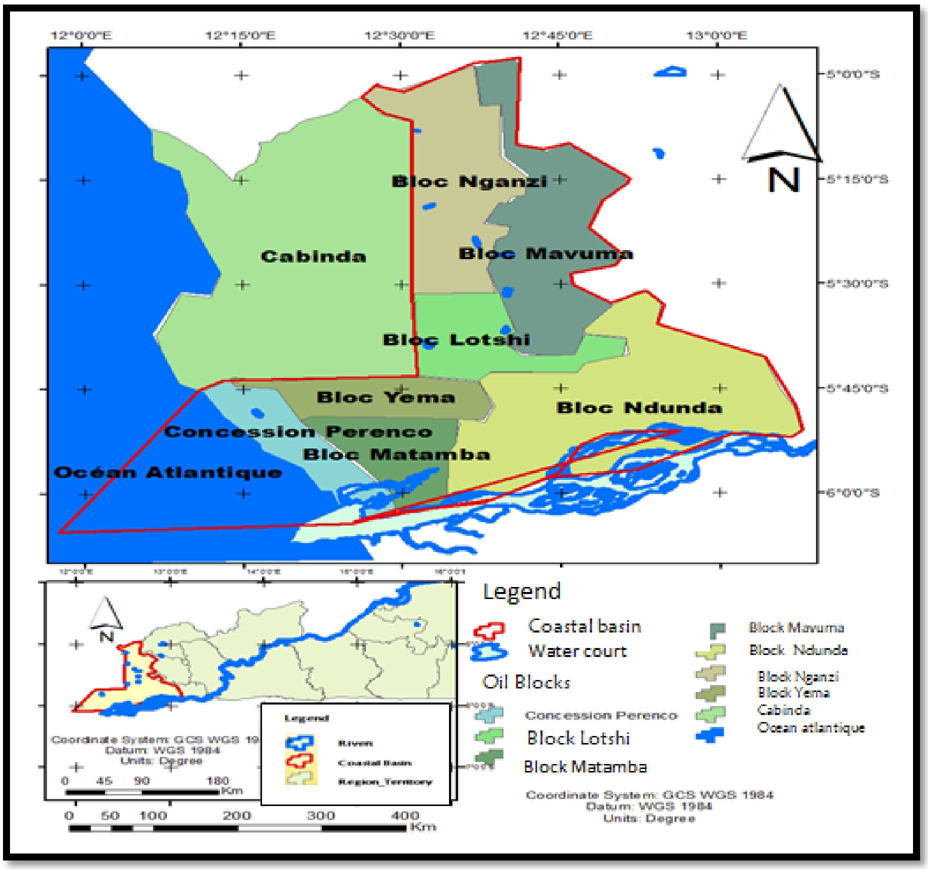

Figure 1. Map of oil blocks in the DRC coastal basin

The coastal basin is located in the province of Central Kongo between longitudes 11°15' and 12°40' East and latitudes 05°00' and 06°05' South. It covers an area of 5,992 km^2 and is subdivided into six oil blocks plus the Perenco concession, which are shown in Figure 1. The Democratic Republic of Congo has around 40 km of coastline. Its importance depends not only on its size but also on its position and resources. For the DRC, the coastal zone begins more than 300 km inland, from the port city of Matadi to Moanda in the Bas-Fleuve district [12]. This coastline occupies a key strategic position for access by sea, with the mouth of the Congo River, the largest river in Africa. Its 68,400 km^2 exclusive economic zone is rich in natural and biological resources.

2. MATERIALS AND METHOD

All scientific paper requires a certain logical method on the part of its author, as well as the various means used to collect the data:

- Historical method: this method enabled us to learn about the history of the coastal basin and the field in which our reservoir is located;
- Data collection: the data used for this study were taken from several Perenco-Rep reports. The data relate to fluid flows in the Turonian reservoir of the Liawenda Field and the presentation of the Coastal Basin;
- Data processing: this stage enabled us to draw up maps and graphs and to calculate certain parameters for understanding fluid flow in the Turonian reservoir;
- Interpretation: this stage involves understanding the flow pattern of the fluids in the Turonian reservoir of the Liawenda Field.

3. RESULTS AND DISCUSSION

3.1. The productive reservoirs of the Liawenda field

The Liawenda field has an anticlinal geological structure with two productive horizons: the Kinkasi formation of Cenomanian age and the Liawenda formation of Turonian age. These horizons are characterised by a complex lithology of calcareous clays, limestones and siltstones with lateral continuity of the layers.

3.2. Turonian reservoir

The Turonian reservoir has an anticlinal structure with very few barriers (faults). The reservoir is composed of clay, carbonaceous silt and clay. The porosity of the oil-bearing zones is between 19 and 25% with an oil saturation of 40 and 65% and an average horizontal oil permeability of 5 to 12 mD. This reservoir has a total of 6 layers, subdivided into zones (Z1 to Z6), and is located between 860 and 1,100 m deep. The Z1 layers and the bottom of Z2 contain water, the top of Z2 to the bottom of Z5 contain oil, while the top of Z5 and Z6 are waterlogged. The column of oil contained in the producing layers is approximately 40 m high.

3.3. Production at Liawenda Field

Table 1 shows the producing and injector wells in the two large reservoirs of the Liawenda Field.

Table 1. Number of wells on the Liawenda field [13]

	Turonian	***Cenomanian***	***Total***
Producers	102	15	117
Injectors	51	9	60
Total	153	24	177

3.4. Initial development

The initial strategy for the applied development of injection was the "inverted seven spot pattern" comprising 6 producer wells placed in a hexagon and an injector well in the centre with a spacing of 100m. The initial quantity of oil in place (STOIIP) is estimated at 250 MMSTB. To date, the recovery factor is around 9.5%.

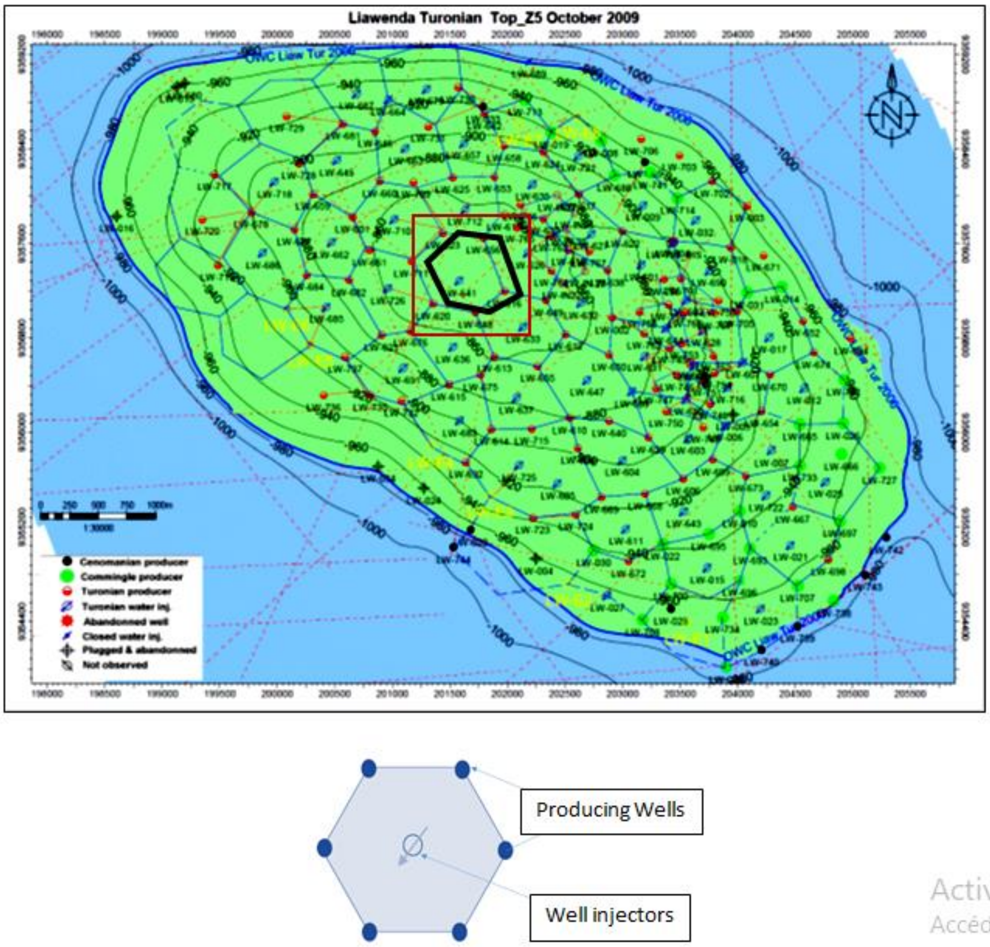

Figure 2. *Seven spot pattern well layout in the Liawenda field* [13]

3.5. Water injection project

Water injection has been shown to be the best way of ensuring optimum oil recovery at Liawenda. There are currently 60 injection wells. The current water injection project at Liawenda aims to increase the flow rate of water injected to 60,000 BWPD [8]. This project will also improve water treatment to ensure good injectivity by avoiding clogging of the formation and pipes [13]. The crucial parameter for the success of this project is the injectivity of the wells. Pilot acidification work on 8 injector wells has been carried out with fairly satisfactory results in terms of improving injectivity. However, we are still a long way from the 1,000 BWPD/well required to achieve the 60,000 BWPD target. The following graphs show the evolution of annual production in the Liawenda field since 1996, when injection began. The field reached its production peak in 2006 (+2,700,000 barrels per year) with 160 producing wells (Turonian and Cenomanian) and 41 injector wells [3].

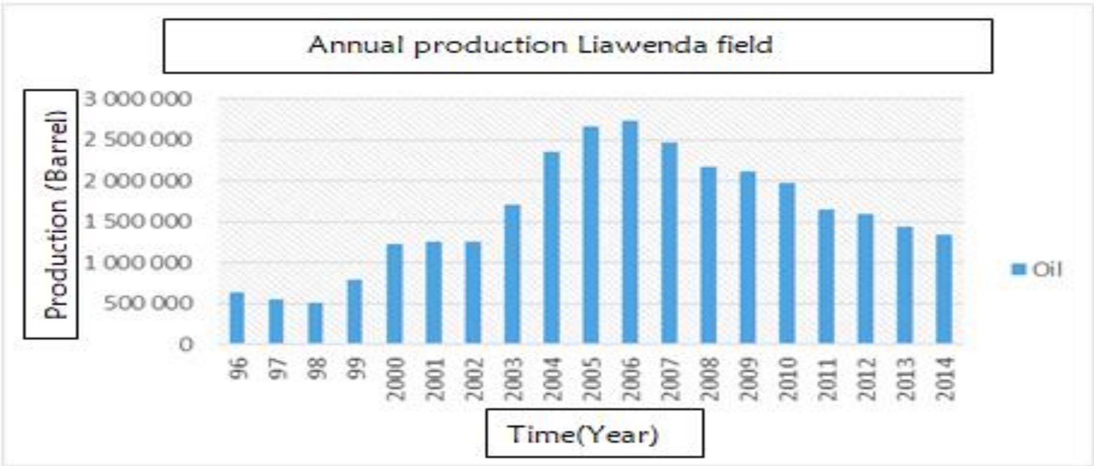

***Figure 3**. Graph of annual production source* [13]

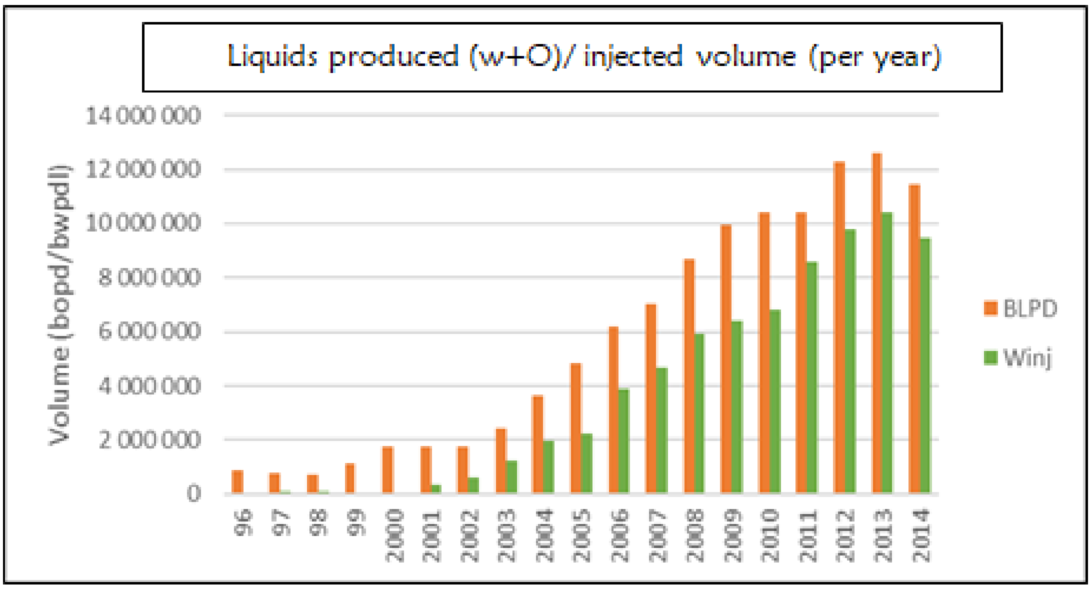

***Figure 4.** Graph showing annual liquid production volumes and water injected* [13]

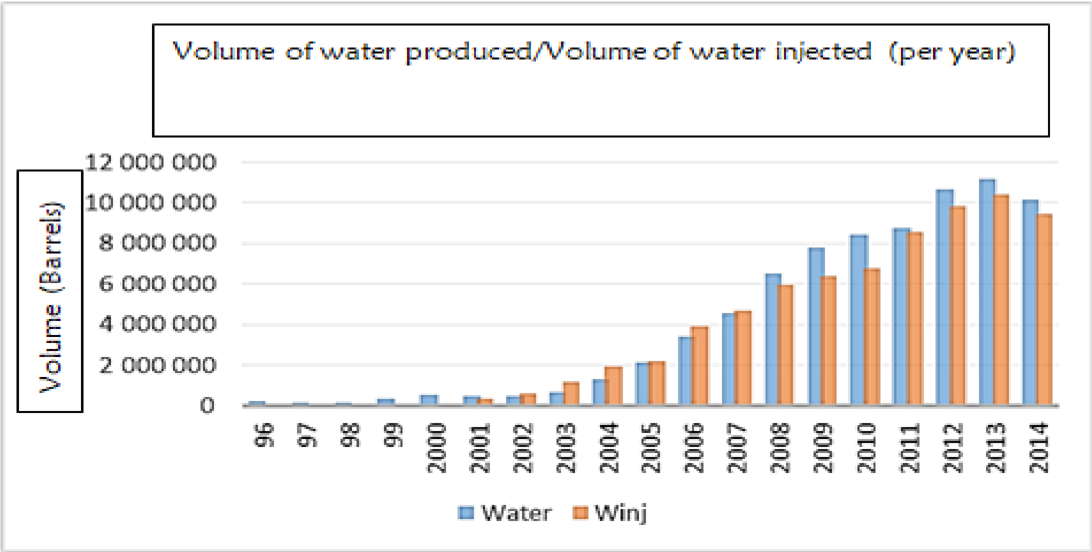

Figure 5. *Graph of volume of water produced and injected per year* [13]

3.6. Cartographic presentation of data Liawenda Field isobath model

The isobath map model can be used to deduce the movement of hydrocarbons. This movement follows a main path by which the fluid moves from bottom to top as a result of the difference in capillary pressures. This is why it is important to draw up an isobath map of the Turonian reservoir of the Liawenda Field in order to identify the high points or zones (Figure 6).

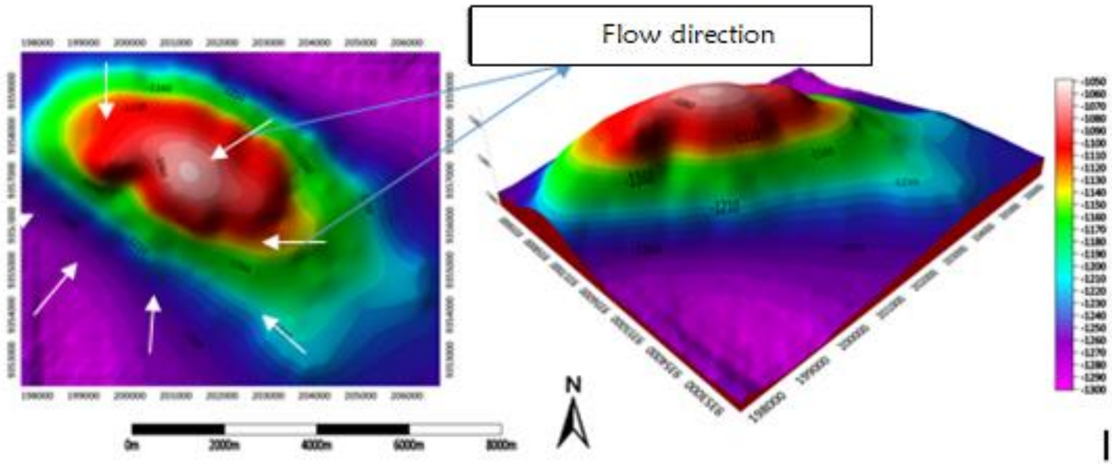

Figure 6. *Isobath map of the Turonian reservoir (Zone 2) at Liawenda Field*

The explanation we can give for this map is that the structure of this reservoir shows an anticline with a long axis running NW to SE and a short axis running NE to SW. The high zone is located in the centre. Fluid accumulation in this reservoir will therefore be more concentrated in the centre. The flow of water injected into this reservoir will follow or is following the same path as the hydrocarbons.

3.7. Model of the slopes of the Liawenda Field Turonian reservoir

The structure of the reservoir is important because it allows the fluid flow to be identified from the lines of greatest slope and its high points. The slope map (figure 7) allows us to locate the zones favourable to the migration and accumulation of hydrocarbons in the Turonian reservoir of the Liawenda Field.

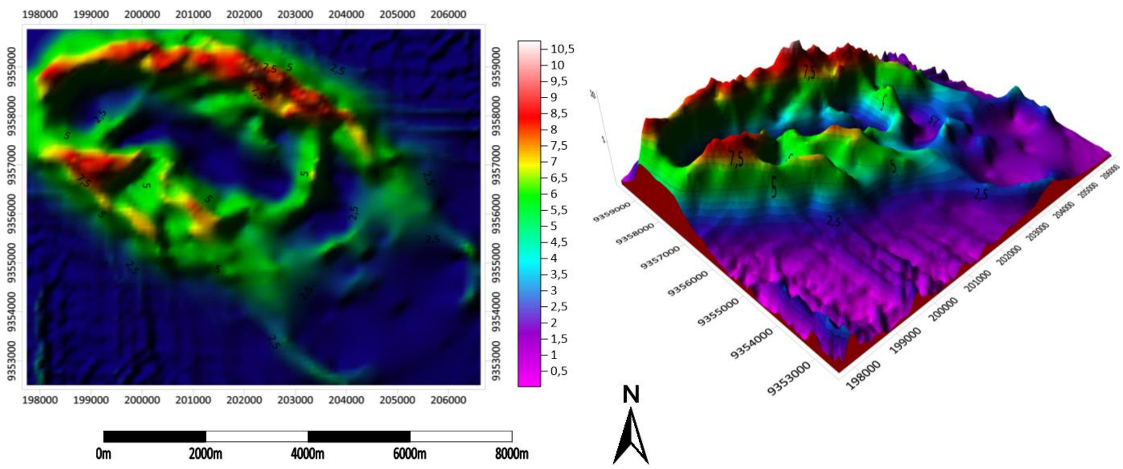

Figure 7. *Map of slopes derived from the isobath map of the Turonian reservoir at Liawenda Field*

The analysis of the slope map is as follows:

- The areas with the least slope are located to the south, east, north-east and centre;
- The steep slope zones are identified by the red lines to the north and west of the low slope zone where the hydrocarbons are located (Figure 8).

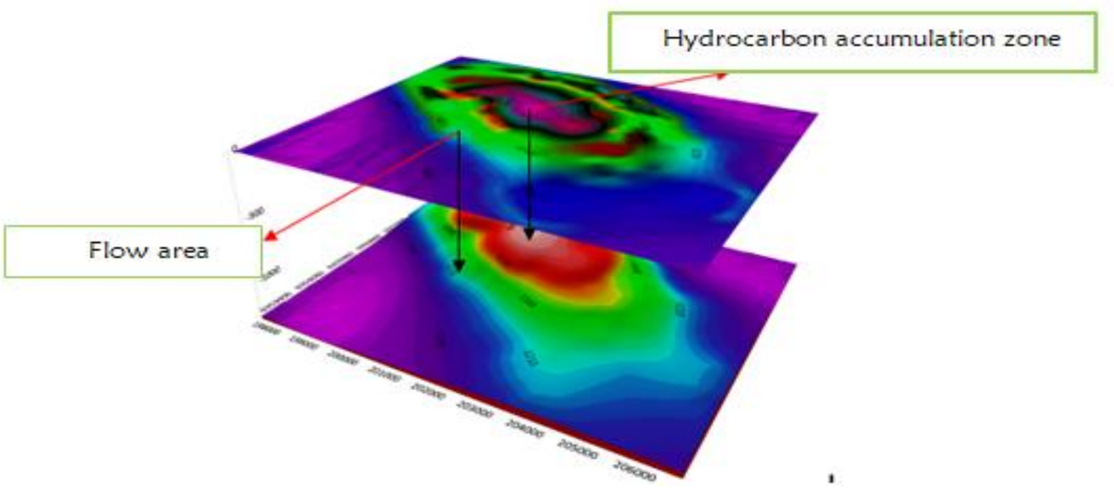

Figure 8. *Map of slopes derived from the isobath map of the Turonian reservoir at Liawenda Field*

4. ANALYSIS OF FLUID FLOW

4.1. Analysis of the performance of the Turonian reservoir in the Liawenda Field

Studying the performance of the Turonian reservoir will enable us to predict fluid flow as a function of downhole pressure. To do this, it is important to know the PVT (Pressure, Volume and Temperature) parameters of the Liawenda Field Turonian reservoir. The PVT parameters of the Turonian Reservoir are given in Table 2. They are shown below [9], [11].

Table 2. *PVT data for the Liawenda Field Turonian reservoir*

Parameters	***Values/Units***
Structure	Anticline
STOIIP	250 MMstb
Oil viscosity	6 cP
Mobility	3
Pi=Pb	1350 Psi
J	0.46603 std/dpsi (Lw-23)
No gas cap	
Rs	250 scf/stb
Permeability	1-50 mD
Useful thickness	20 m
Boi	1.13

When the reservoir pressure is equal to the pressure at the bottom of the well, the flow becomes two phase, which is the case for the Liawenda Field Turonian reservoir.

We can therefore calculate the maximum flow rate of the Liawenda Field using the formula:

$$Q_{max} = \frac{j * P_i}{1{,}8} \tag{1}$$

We can therefore calculate the RPI using the following formula:

$$p_{wf} = 0{,}125\, p \left[\sqrt{81 - 80\left(\frac{Q}{Q_{max}}\right)} - 1\right] \tag{2}$$

RPNs for different fluids

Using the example of the Lw-23 well, where the oil flow rate is 62 BOPD and the water flow rate is 157 BWPD, we can calculate the production index for the two fluids as follows:

$$J = \frac{Q}{(P_i - P_{wf})} \tag{3}$$

Knowing that the reservoir pressure is equal to 1350 psi, the flow rates of oil and water respectively and the pressure at the bottom of the well *Pwf* = 1217 psi, we can calculate the maximum flow rates and the production index for each fluid [9].

Calculation of the production index and maximum flow rate for the oil

$$J_{oil} = \frac{62}{(1350-1217)} \quad (4)$$

J_{oil}= 0.46616 bbl/psi

$$Q_{max} = \frac{0,46616*1350}{1,8} \quad (5)$$

$$Q_{max} = \frac{629,316}{1,8} \quad (6)$$

$$\mathrm{Q_{max/oil}} = 349,62 \text{ bbld}$$

For water

$$\mathrm{J_{water}} = \frac{157}{(1350-1217)} \quad (7)$$

$\mathrm{J_{water}}$ = 1.18 bbl/psi

$$Q_{max} = \frac{1,18*1350}{1,8} \quad (8)$$

$$Q_{max} = \frac{1593}{1,8} \quad (9)$$

$$Q_{max/water} = 885\ bbld \quad (10)$$

Based on the above results, we can plot the RPN for water and oil. Table 3 and table 4 shows the values for *Pwf* and flow rate for water and oil [4].

Table 3. *Results of the water RPN*

Pwf/water	*Qwater*
1350	0
1262,74792	100
1169,82053	200
1069,94116	300
961,26794	400
840,965451	500
704,239139	600
541,668738	700
328,522087	800
0	885

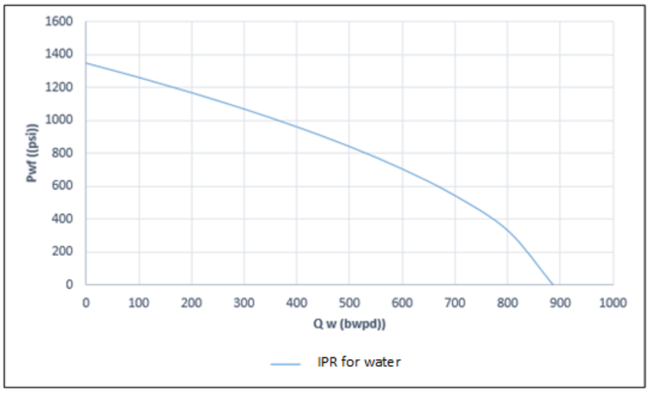

Figure 9. *IPR for water*

***Table 4**. IPR results for oil.*

Qo (bopd)	*Pwf/oil*
0	1530
30	1455,4
60	1377,4
90	1295,2
120	1208,2
150	1115,4
180	1015,5
210	906,53
240	785,5
270	647,17
300	480,96
330	256,84
349,62	0

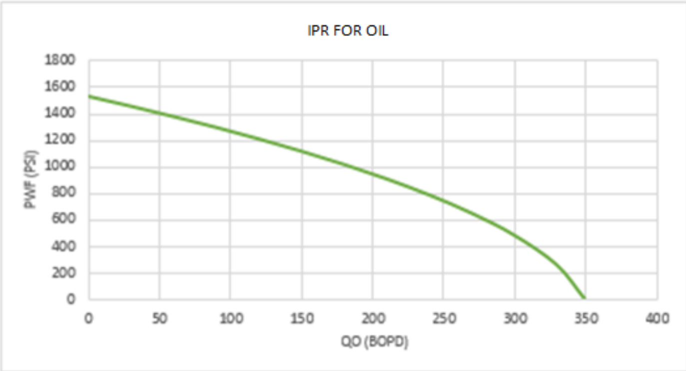

***Figure 10.** IPR for oil*

The RPNs illustrated above show that the maximum flow rate for oil is 349.62 BOPD and for water is 885 BWPD at 0 psi. There is a difference of 535.38 BOPD for the oil reduction to become equivalent to the water reduction. This shows that water flows faster than oil. In fact, with a flow rate of 200 BOPD or BWPD, the pressure at the bottom for water is 1080 psi and 815 psi for oil [6].

4.2. Analysis of relative permeability

Relative permeability data as a function of saturation taken during well testing in the Liawenda Field are presented in the table 5 [7].

***Table 5**. Relative permeability data as a function of saturation*

Krw	**Kro**	**So**	**Sw**
0	0.85	0.75	0.25
0.28	0.525	0.625	0.375
0.415	0.305	0.5	0.5
0.675	0.175	0.325	0.675
0.875	0	0.20	0.8

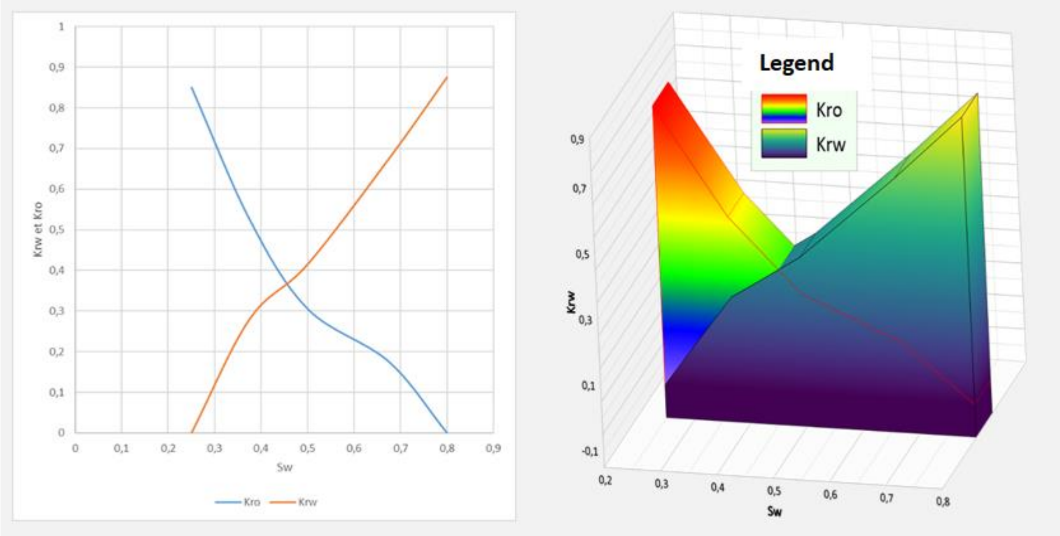

***Figure 11**. Evolution of relative water and oil permeability as a function of water saturation*

Determining flow capacity

The total flow capacity can be determined by the equation:

$$- Kro + Krw < 1 \quad (11)$$

which shows that the two fluids interfere with each other during their simultaneous movement, so the total flow capacity is reduced [1], [11]. The results of the determination of the flow capacity in the Turonian reservoir of the Liawenda field are shown in Table 6.

***Table 6**. Determination of flow capacity in the Turonian reservoir of Liawenda Field*

Krw	Kro	Krw-Kro	Report
0	0.85	-0.85	Reduced flow capacity
0.28	0.525	-0.245	Reduced flow capacity
0.415	0.305	0.11	Reduced flow capacity
0.675	0.175	0.5	Reduced flow capacity
0.875	0	0.875	Reduced flow capacity

Calculation of fractional flow in the Turonian reservoir of Liawenda Field

Knowing the fractional flow rate makes it possible to calculate the displacement efficiencies in the Turonian reservoir of the Liawenda Field.

The formula for calculating fractional flow rates is given by [5]:

$$f_w = \frac{1-8{,}4.10^{-4}\left(\frac{Ak}{Q_T}\right)\left(\frac{k_{ro}}{\mu_0}\right)(\rho_w-\rho_0)\sin\alpha}{1+\left(\frac{k_{ro}}{k_{rw}}\right)\left(\frac{\mu_w}{\mu_o}\right)} \quad (12)$$

Such as:

- *Fw:* fractional water flow rate
- *Krw:* relative water permeability
- *Kro:* relative oil permeability

The basic condition:

- *μw:* water viscosity (cP) μ*w*= *c*P
- *μo:* oil viscosity (cP) μ*o*= *c*P

Calculation of the dip formations of the Turonian reservoir of the Liawenda field

The dip is calculated from the shape of the geological layers of the Turonian reservoir in the seismic profile (Figure 12).

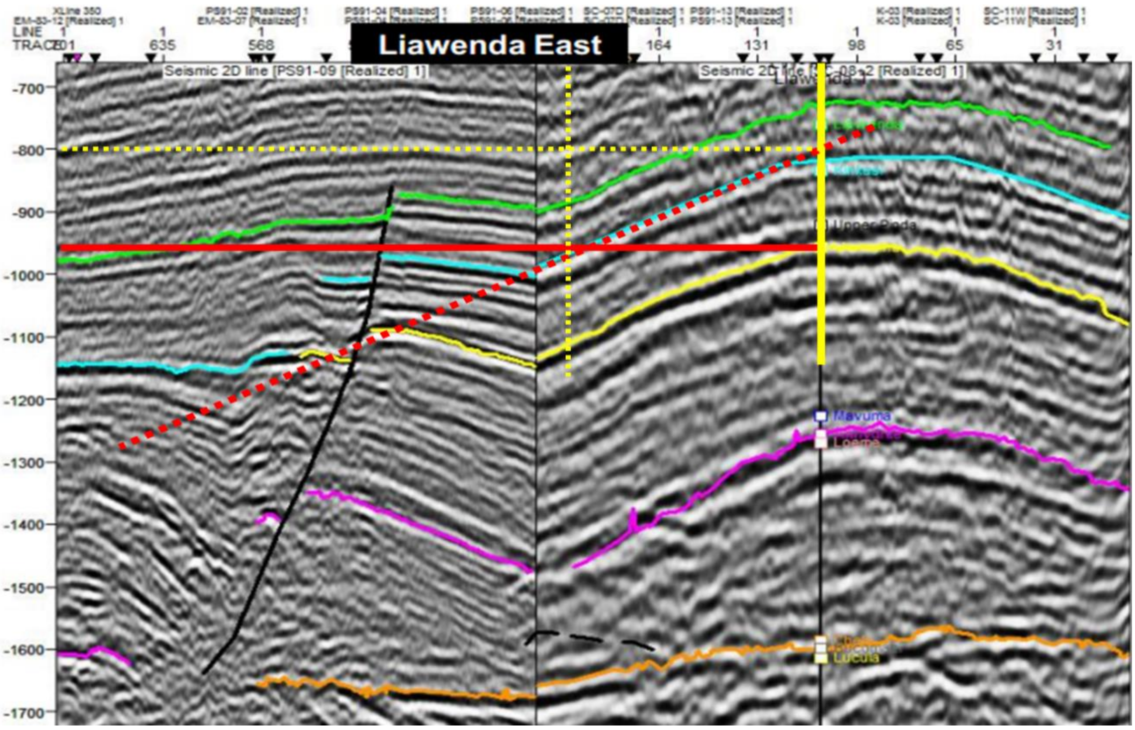

Figure 12*. Seismic profile across the Liawenda Field (Perenco-Rep. 2009)*

Calculation of the slope:

$$\text{tg}\alpha = \frac{Y}{X} = \frac{3{,}4\ cm}{6{,}84\ cm} = 0.497076 \qquad (13)$$

$$\alpha = \text{arctg}\ (0{,}497076) = 26.430868\ °$$

By replacing the values found in the fractional flow formula. We find the results illustrated in Table 7.

***Table 7**. Fractional flow results*

Krw	Kro	Krg	Qt	Pw	FW	K	A
0	0.85	0	1550	1.05	0	10	39831040.9
0.28	0.525	0.0545	1550	1.05	0.68825442	10	39831040.9
0.415	0.305	0.150122	1550	1.05	0.82716184	10	39831040.9
0.675	0.175	0.325	1550	1.05	0.90745358	10	39831040.9
0.875	0	0.5	1550	1.05	1	10	39831040.9

Po	Sina	Mw	Mo
0.92	0.96305541	0.35	6
0.92	0.96305541	0.35	6
0.92	0.96305541	0.35	6
0.92	0.96305541	0.35	6
0.92	0.96305541	0.35	6

Figure 13 below shows that the permeability to oil and water increases constantly. It is not greatly affected by the presence of water, whereas water permeability is more affected by the presence of oil. [14], [16]

We were therefore able to draw up a figure showing the evolution of the fractional flow rate in relation to water saturation (Figure 13).

With:

Swi = 0.25 = 25 % pore water saturation;

Swf = 0.375 = 37.5 % water saturation at the front;

SwM = 0.80 = 80 % maximum water saturation;

Swm = 0.42 = 42 % average water saturation behind the front;

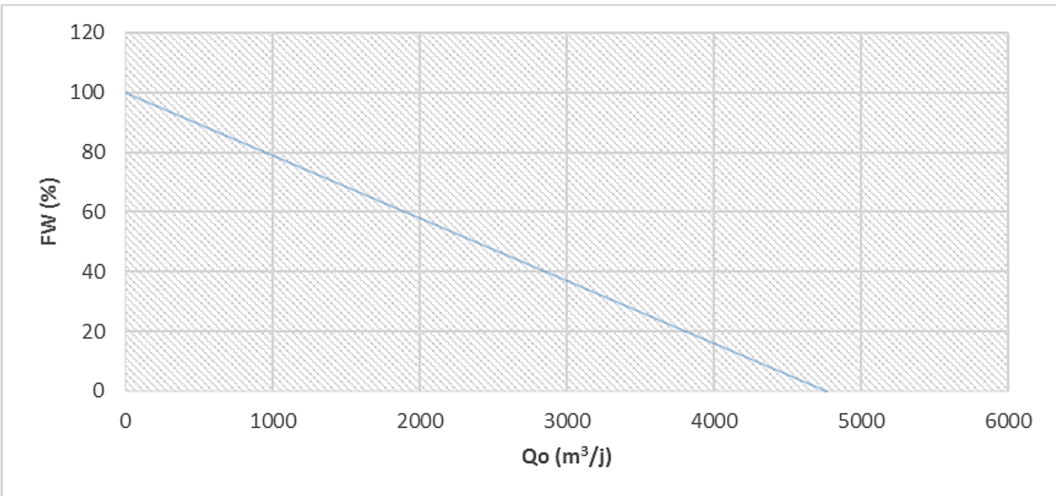

***Figure 13**. Line linking fractional flow and oil flow in the Turonian reservoir of the Liawenda Field.*

The speed of advance of the front is obtained by calculating *dfw/dsw* from *fw*. Calculating the slope of the Welge tangent gives:

$$\left(\frac{df_w}{ds_w}\right) sw_f = \frac{1}{(\text{Swm}-\text{Swi})} \tag{14}$$

$$\left(\frac{df_w}{ds_w}\right) sw_f = \frac{1}{(0{,}42-0{,}25)} \tag{15}$$

$$\left(\frac{df_w}{ds_w}\right) sw_f = 5.88235 \tag{16}$$

Calculating the velocity at the front

The formula is given by:

$$v_f = \frac{Q_T}{A*\emptyset(S_{Wm}-S_{Wi})} \tag{17}$$

- *Qt* =1150 m3/d
- *A*= 337367.578717 m ^{2}
- *Φ*=25%= 0.25

Replacing these values in the speed formula gives:

$$v_f = \frac{4770}{337367{,}578717*0{,}25(0{,}42-0{,}25)} \tag{18}$$

$$v_f = \frac{4770}{14338{,}1221} \tag{19}$$

$$v_f = 0{,}33268\ m/d \tag{20}$$

Calculation of water breakthrough time

Since the distance between the injector wells and the producer wells is 100 m [10] the water breakthrough time will be:

$$T_{bt} = \frac{X}{Vf} \tag{21}$$

$$T_{bt} = \frac{100}{0{,}33268} \tag{22}$$

$$T_{bt} = 300.589562 \text{ days} \tag{23}$$

Tbt = 9 month 26 days 11 hours 19 min 32 sec

We can draw the straight line that links the fractional water flows and the oil flows in the Turonian reservoir of Le Champ using the following relationship:

$$\frac{Q_o}{Q_T} = 1 - Fw \tag{24}$$

So,

$$Q_o = Q_T(1 - Fw) \tag{25}$$

Table 8. *Evolution of Qo function of fractional flow in the Turonian reservoir of Liawenda Field*

Qo (m3/j)	***Fw (%)***
4770	0
4293	10
3816	20
3339	30
2862	40
2385	50
1908	60
1431	70
954	80
477	90
0	100

5. CONCLUSIONS

When an oil field is exploited the pressure decreases over time. In this case, methods are used to improve and maintain the pressure within the reservoir. One of these methods is water injection, a technique that generally increases pressure and stimulates oil production. The DR Congo Coastal Basin in the Province of Kongo Central has several onshore and offshore oil fields. These include the Liawenda field, which has several wells producing from the two main reservoirs (Turonian and Cenomanian).

The Liawenda field has a total of 186 wells with an annual production of 3.009.553 barrels. Having started production in these two reservoirs for a long time, the field experienced a drop in pressure, which is why water injection techniques were used. Despite the application of this technique, we have observed excessive production of water in relation to the oil.

This scientific paper based on a study of the fluid flow model in the Turonian reservoir of the Liawenda field using water injection data yielded the following results after processing and interpretation:

- The flow of fluids is directed towards the centre of the anticline of the Turonian reservoir as a result of the dip of the layers and the difference in capillary pressures;
- The fluids inside the reservoir interfere with each other because the difference between *Krw* and *Kro* found are less than 1;
- The time and speed of fluid flow from the injector wells to the producer wells are less important;
- Fluid displacement capacities become significant from the maximum breakthrough;
- Mobility values greater than 1 show that water moves faster than oil;
- The IPRs for the fluids showed that the maximum flow rate for oil is 349.62 BOPD and that for water is 885 BWPD at a pressure of 0 psi. This proves that water flow is faster than oil flow. In view of the above, we propose that the company operating the

field (Perenco-Rep) convert some of the producing wells located around the periphery of the anticline into injector wells in order to increase the flow capacity of the reservoir. Injections of certain chemicals to increase the viscosity of the oils are very important, as they will increase the flow rate of the oils relative to water.

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